Silent Corruptions

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Corruptions

- Corruption: data is changed unintentionally
- mechanisms to detect/correct
  - checksum (CRC32, MD5, SHA1, ...)
  - ECC
  - multiple copies with quorum
- detection: SW/HW-level with error messages
- correction: SW/HW-level with warnings
- Silent corruption: data is changed unintentionally **without** any errors/warnings!

Corruption Sources

- hardware errors (memory, CPU, disk, NIC)
- data transfer noise (UTP, SATA, FC, wireless)
- firmware bugs (RAID controller, disk, NIC)
- software bugs
  - kernel
    - VM
    - filesystems
    - block layer
- application: crash, etc. (not discussed)

Expected Bit Error Rate (BER)

- NIC/link: 10^{-10} (1 bit in ~1.1 GiB)
  - checksummed, retransmit if necessary
- memory: 10^{-12} (1 bit in ~116 GiB)
  - ECC
- desktop disk: 10^{-14} (1 bit in ~11.3 TiB)
  - various error correction codes
- enterprise disk: 10^{-15} (1 bit in ~113 TiB)
  - various error correction codes
- quotes from standards/specifications

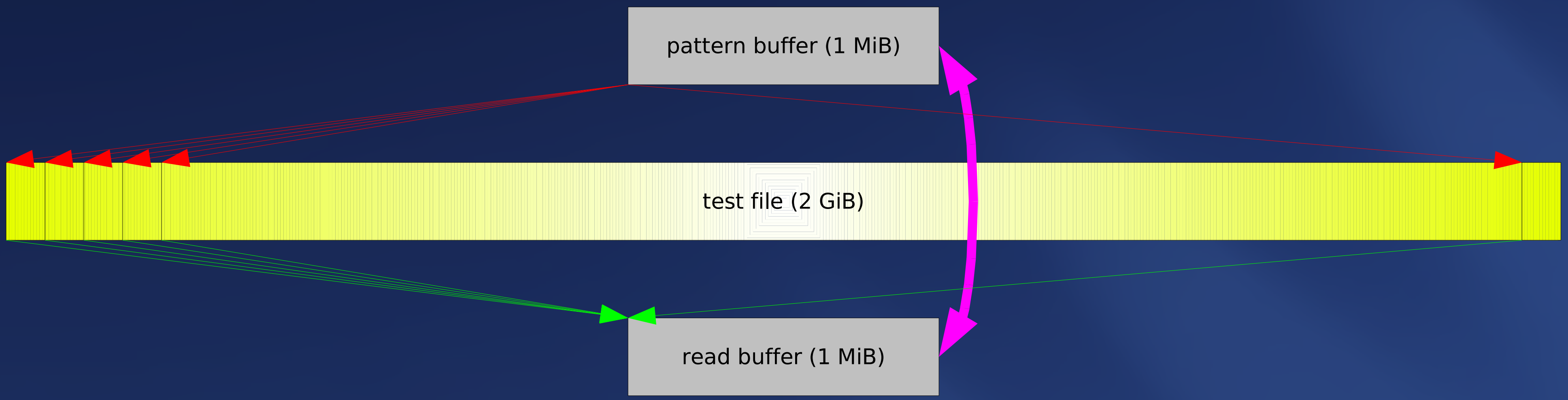
It Already Happened to Us

- “DON'T PANIC!”
- acknowledge user observation (if any)
- assess the problem
  - develop/deploy tools for data collection
- estimate the scale of the problem
- research the cause (correlation) and impact
- evaluate possible solutions
- deploy possible solutions

fsprobe(8)

- probabilistic storage integrity check
  - write known bit pattern
  - read it back
  - compare and alert when mismatch found
- low I/O footprint for background operation
- keep complexity to the minimum
- use static buffers
- attempt to preserve details about detected corruptions for further analysis

fsprobe cycles




```
0x55 [01010101]
0xAA [10101010]
0x33 [00110011]
0xCC [11001100]
0x0F [00001111]
0xF0 [11110000]
```

ONE cycle completes in 2*2048 sec = 1 hour 8 minutes

SIX cycles in (2*2048+300)*6 sec = 7 hours 20 minutes

Investigation

- probe deployed on ~3500 nodes
- ~1000 incidents reported (total 41PB traffic)
- ~170 nodes affected
- incidents now tracked in a relational DB
- steady flow of 2-5 incidents per day
- multiple types of corruptions observed
- affected systems are very diverse
  - SLC3/SLC4/RHEL4, XFS/ext3, 3ware/ARECA
- some corruptions are transient

Corruption Types

- Type I
  - single/double bit errors
  - usually bad memory (RAM, cache, etc.)
- Type II
  - small, 2^n-sized chunks (128-512 bytes)
  - of unknown origin
- Type III
  - multiple large chunks of 64K, “old file data”
- Type IV
  - various sized chunks of zeros

Type I

- usually persistent
- bit(s) have flipped in a byte
- Single Bit Error (SBE)
- Double Bit Error (DBE)
  - DBEs are 3x more common than SBEs
  - a single case of a triple bit error was observed
- 1→0 transition more frequent than 0→1
- strong correlation with bad memory (verified)
- happens with expensive ECC-memory too

Type I Example

```
00000000  33 33 33 33 33 33 33 33  33 33 33 33 33 33 33 33  |3333333333333333|
*
35285650  33 33 33 33 33 33 33 33  33 33 33 33 33 33 22 33  |33333333333333"3|
35285660  33 33 33 33 33 33 33 33  33 33 33 33 33 33 33 33  |3333333333333333|
*
80000000
```

Type II

- usually transient
- small chunks of “random” looking data
    - ...but can go up to 128K
- sometimes identifiable user data
- observed in vicinity of OOM situations
- possible SLAB corruption?

Type II Example

```
00000000  cc cc cc cc cc cc cc cc  cc cc cc cc cc cc cc cc  |................|
*
000def00  f1 2b f8 2b cd 43 38 38  e3 43 bd 8d b0 01 12 0a  |.+.+.C88.C......|
000def10  af 6e c3 b6 57 3e 5f fa  e3 d6 e8 7b ef 5b 6f 3c  |.n..W>_....{.[o<|
000def20  e4 42 42 0c e9 22 2e f1  d0 c6 a5 55 f2 f3 a7 38  |.BB..".....U...8|
000def30  b5 43 77 c9 5d 4e 16 a2  39 79 5f 31 10 65 b8 e4  |.Cw.]N..9y_1.e..|
000def40  9c 8a 94 a0 73 2d f7 ad  d9 12 31 2b f5 db b4 18  |....s-....1+....|
000def50  e4 ff c6 14 ee 00 d6 c0  7a c8 8e c0 3f 73 32 73  |........z...?s2s|
000def60  79 b3 63 d8 4c 8f 5d d8  c5 1e e4 5f 0e 2a 1d 94  |y.c.L.]...._.*..|
000def70  f8 2d 64 e7 10 e1 6b 89  da b3 fb 0b 48 59 d4 df  |.-d...k.....HY..|
000def80  9a 0c a4 ae 18 c5 40 a5  70 6b 19 d3 b9 f7 a2 b3  |......@.pk......|
000def90  44 df 2a 50 a1 55 31 02  57 d6 19 43 80 b0 0a 89  |D.*P.U1.W..C....|
000defa0  fe c2 34 ed cc 73 2e 64  38 89 6e 5a be d7 3b c4  |..4..s.d8.nZ..;.|
000defb0  db dd 58 42 a1 62 2f 6d  92 6a ed 9b 23 6e 1e 79  |..XB.b/m.j..#n.y|
000defc0  d8 88 38 86 92 2f af 29  a1 0f c0 21 46 fc 3a e3  |..8../.)...!F.:.|
000defd0  ac 17 0a f1 c3 31 89 82  59 e5 89 b9 9e fa 45 b9  |.....1..Y.....E.|
000defe0  54 d6 6a 72 b9 6a d6 1f  ff cb 6a 10 1e bd 66 87  |T.jr.j....j...f.|
000deff0  68 80 64 b0 53 97 74 72  ee f6 87 9f 23 47 cb 48  |h.d.S.tr....#G.H|
000df000  cc cc cc cc cc cc cc cc  cc cc cc cc cc cc cc cc  |................|
*
00100000
```

Type III

- usually persistent, comes in bursts
- strong correlation: I/O command timeouts
  - 3ware hides timeouts, look at extended diag
  - also observed on plain SATA systems
  - ...sometimes with failed READ commands!
- “previous” data from earlier cycles (sometimes multiple cycles old!) or from another location on disk
- seems to match RAID stripe size (64K)
  - observed on 16K chunk RAID arrays as well

Type III Example

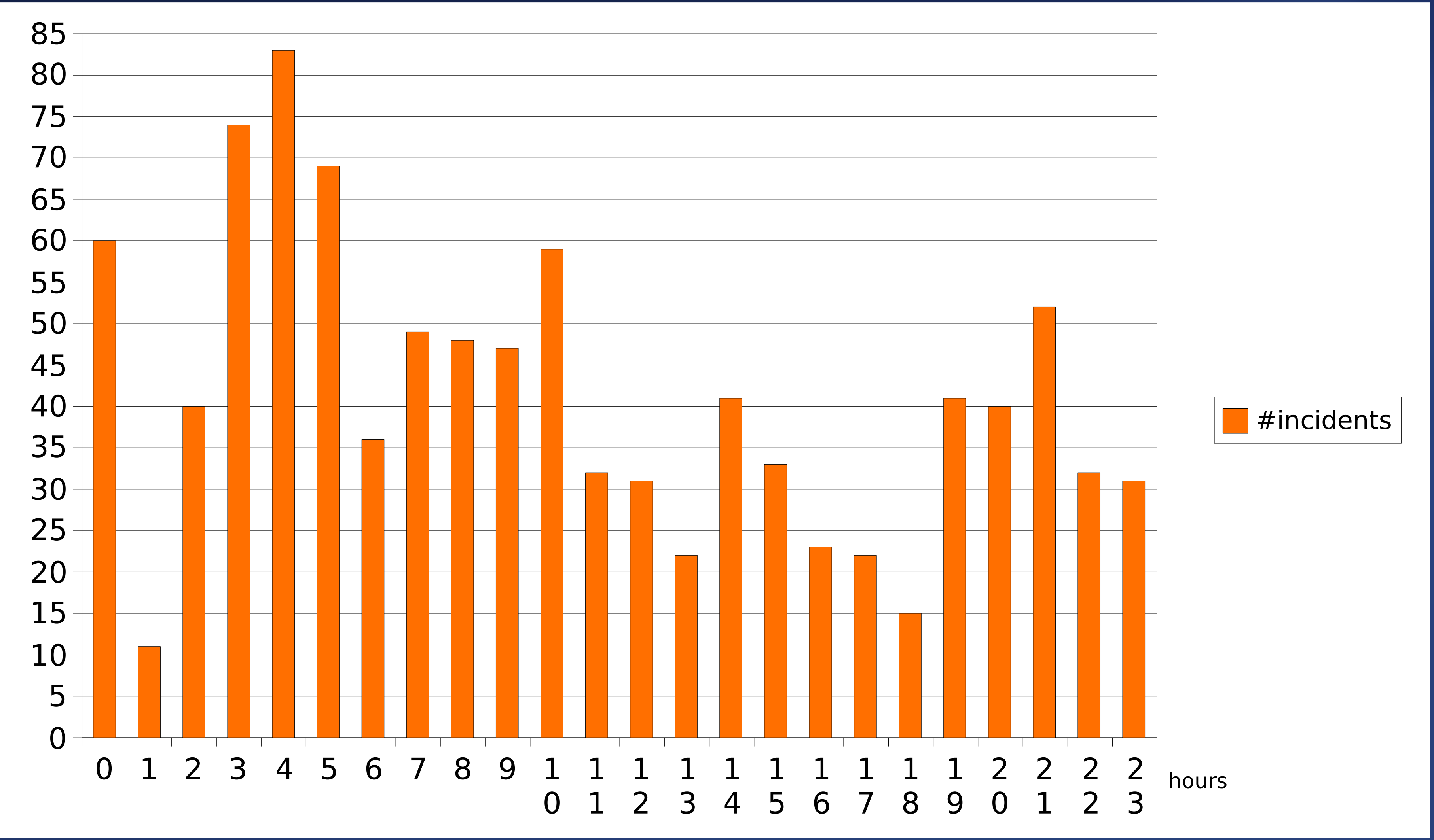
```
00000000  cc cc cc cc cc cc cc cc  cc cc cc cc cc cc cc cc  |................|
*
34205200  33 33 33 33 33 33 33 33  33 33 33 33 33 33 33 33  |3333333333333333|
*
34215200  cc cc cc cc cc cc cc cc  cc cc cc cc cc cc cc cc  |................|
*
34265200  33 33 33 33 33 33 33 33  33 33 33 33 33 33 33 33  |3333333333333333|
*
34275200  cc cc cc cc cc cc cc cc  cc cc cc cc cc cc cc cc  |................|
*
342c5200  33 33 33 33 33 33 33 33  33 33 33 33 33 33 33 33  |3333333333333333|
*
342d5200  cc cc cc cc cc cc cc cc  cc cc cc cc cc cc cc cc  |................|
*
34325200  33 33 33 33 33 33 33 33  33 33 33 33 33 33 33 33  |3333333333333333|
*
34335200  cc cc cc cc cc cc cc cc  cc cc cc cc cc cc cc cc  |................|
*
34385200  33 33 33 33 33 33 33 33  33 33 33 33 33 33 33 33  |3333333333333333|
*
34395200  cc cc cc cc cc cc cc cc  cc cc cc cc cc cc cc cc  |................|
*
80000000
```

Type IV

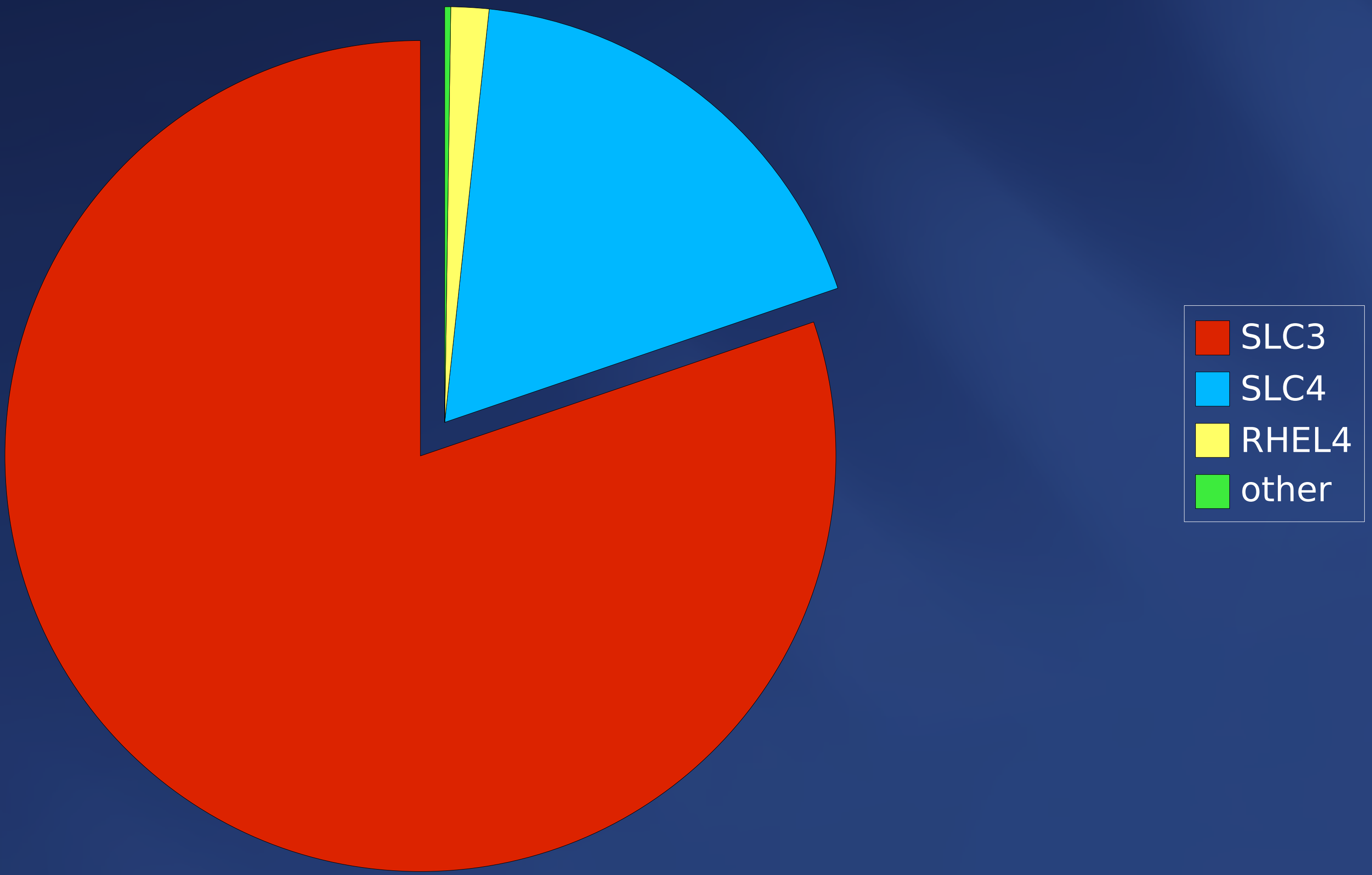
- usually persistent
- relatively recent observations (April)
- ...not sure yet this warrants another category

Type IV Example

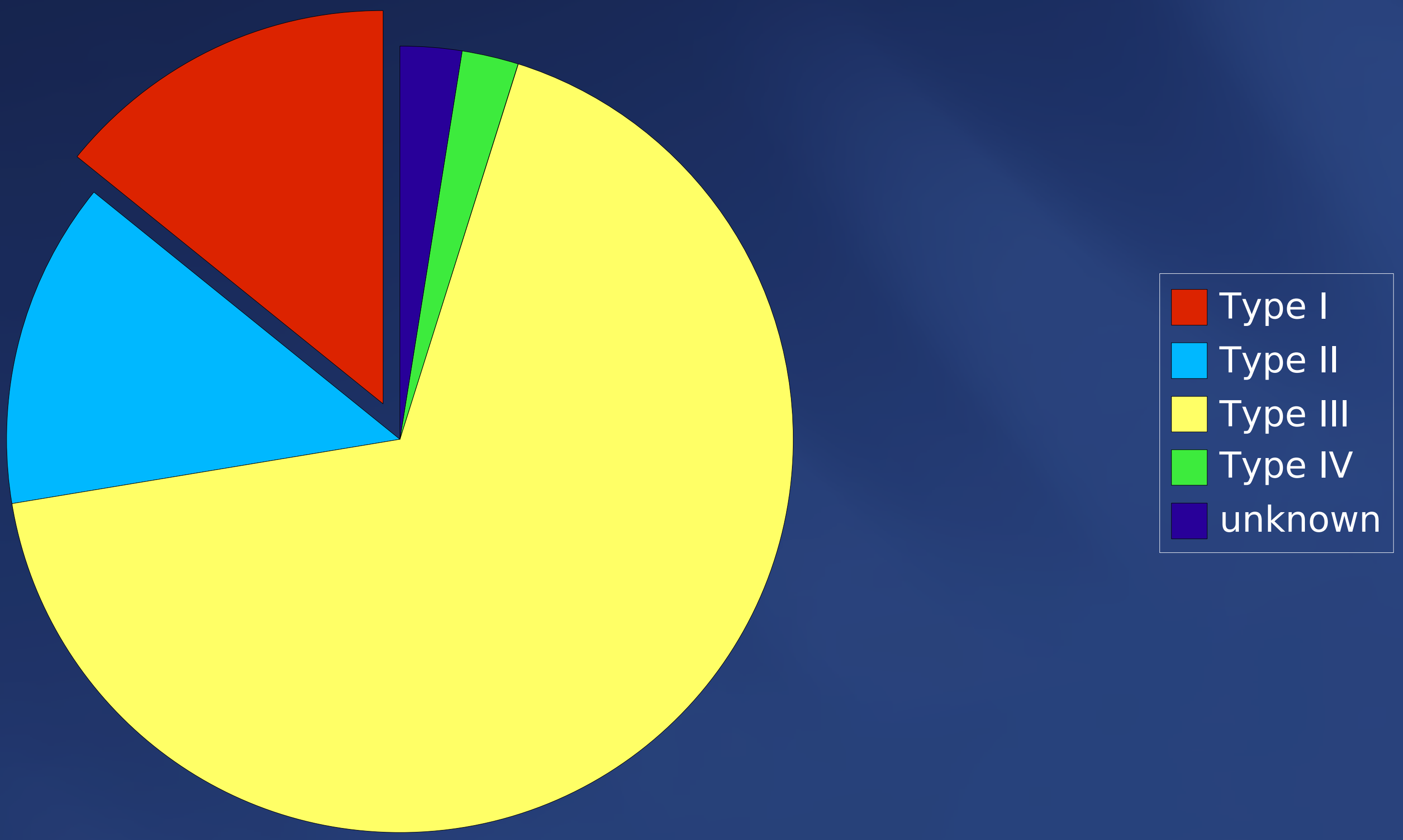
Corruption Time Distribution



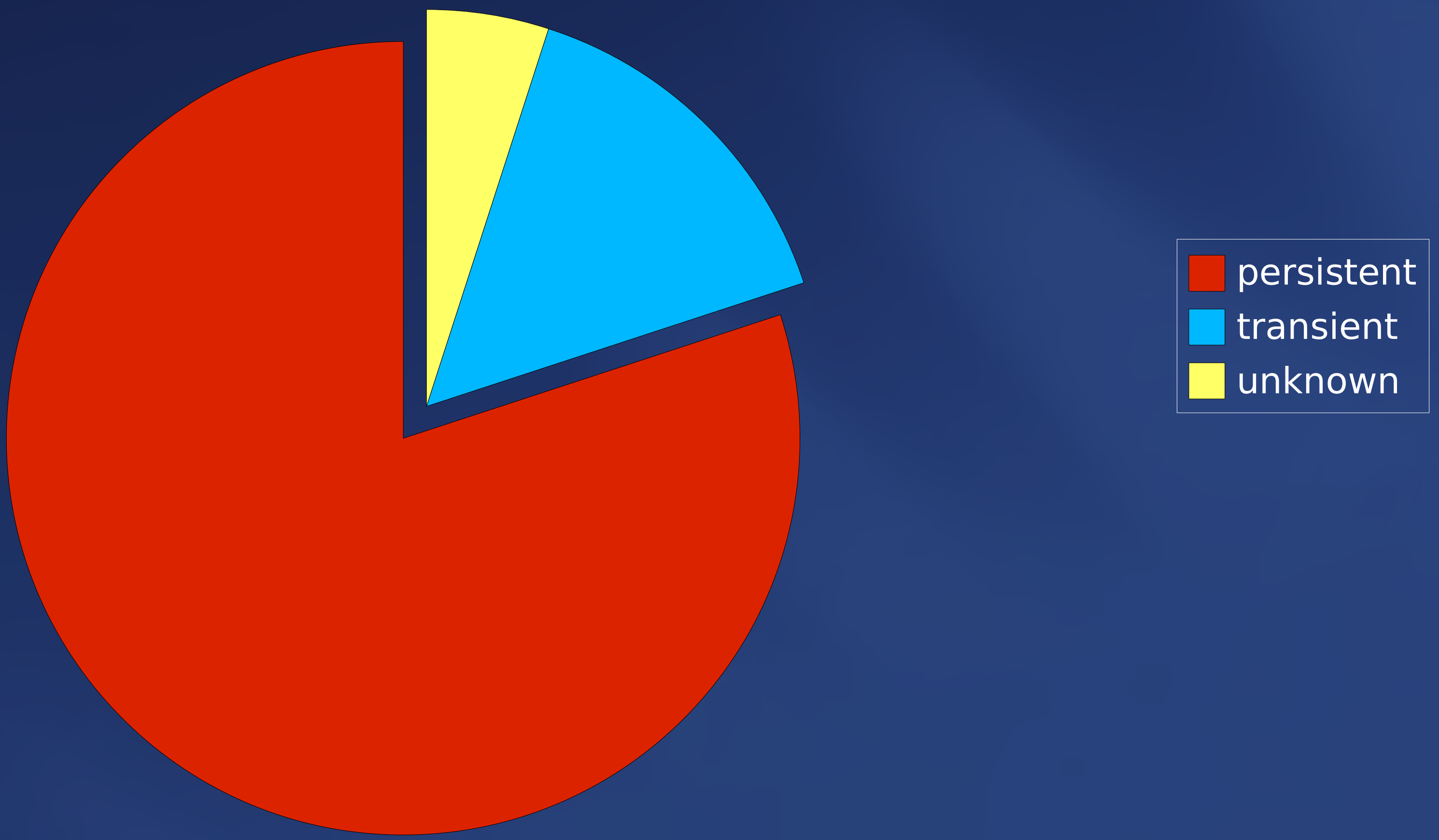
Operating Systems



Corruption Types



Corruption Persistence



Where From?

user space

VM
filesystems
block layer
SCSI layer
low-level drivers
controller firmware
storage firmware

physical magnetic media

What Can Be Done?

- self-examining/healing hardware (?)
- WRITE-READ cycles before ACK
- checksumming? → not necessarily enough
- end-to-end checksumming (ZFS has a point)
- store multiple copies
- regular scrubbing of RAID arrays
- “data refresh” re-read cycles on tapes
- ...generally accept and prepare for corruptions

Conclusions

- silent corruptions are a fact of life
- first step towards a solution is detection
- elimination seems impossible
- existing datasets are at the mercy of Murphy
- correction will cost time AND money
- effort has to start now (if not started already)
- multiple cost-schemes exist
    - trade time and storage space (à la Google)
    - trade time and CPU power (correction codes)

Departing Words

"Trust, but verify"

— Ronald Reagan

Questions?

Thank you and have a nice filesystem (without corruptions)!

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